International Journal of Engineering & Technology, 7 (3.36) (2018) 62-67

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper

A Feasibility Study on partially substituted Coarse Aggregate with Oil Palm Shell in Coconut Fiber Reinforced Concrete

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Abstract

In the search of alternative materials for the replacement of conventional coarse aggregate, the feasibility of utilizing agricultural waste products was looked into in the effort of producing a more environmentally friendly and less dense concrete. Mechanical properties of partially substituted coarse aggregates using oil palm shell (OPS) in a concrete composite reinforced with a low volume fraction of coconut fibre (CF) have been studied for its feasibility as an alternative solution to the problem. Analysis on the impact of compressive strength, flexural strength, density and Young's modulus have been conducted on hardened coconut fibre reinforced concrete (CFRC) at 15% and 25% substitution by volume of conventional coarse aggregates with OPS. The properties of the composite concrete were evaluated with reference to the control sample, CFRC reinforced with 0.2% fibre volume fraction. The results have shown that it is feasible to produce a sustainable grade 30 concrete of lower density with CFRC at 25% level of OPS substitution.

Keywords: *Concrete Composites; Coconut Fibre; Feasibility; Mechanical Properties; Oil Palm Shell.*

1. Introduction

The characteristic of concrete is that it is strong in compression but weak in tension. This causes the concrete to be brittle. The brittleness of concrete can cause poor resistance to crack propagation, poor fracture toughness and low impact strength. Natural coconut fibre (CF) has the potential to solve the brittle characteristic of concrete as an alternative to conventional steel rebar. This method has already been introduced as reinforcement in cement matrices for a number of years [1, 2]. The inclusion of fiber alters the fiber- matrix composite, which in turn improves its flexural strength. It has been observed that an increment of 13.7% in compressive strength in coconut fibre reinforced concrete (CFRC) with 2% fibre volume fraction as compared to plain concrete [3]. Coconut fiber is natural and plentiful in tropical countries such as Malaysia. It can be obtained from the extraction of the outer shell of a coconut. CFRC can be utilized in the application of roofing materials, partitions, ceiling and exterior wall panels [3]. Additionally, the low bulk density of fibre contributed by the hollow cavity of coconut fibres has an advantage to insulate sound and heat.

A potential material in the replacement of gravel as coarse aggregate is oil palm kernel shell (OPS). OPS has a unit weight of 500- 600 kgm^{-3}, approximately five times less dense than the unit weight of gravel. The density of OPS concrete was found to be 20-25% lower than normal weight concrete [4]. The density reduction in concrete can lower the overall dead load in a building besides easing transportation and erection of structures. Furthermore, overall construction cost can be significantly reduced. At the same time, waste disposal problem can be solved by utilizing this agricultural waste product. The reduction in compressive strength of OPS concrete as compared to that of conventional concrete would exclude its use in structures that require high compressive strength but it is acceptable in applications such as floor slabs, road kerbs, drain blocks and pavement [5].

In light of solving the issue of sustainability in the construction industry, many researches had been carried out to substitute conventional aggregates in concrete. The consumption of natural aggregates was estimated to be between 8-12 billion tonnes yearly after 2010 [6]. Although natural aggregate is widely available around the world, problems such as lack of resources at certain areas, impractical locations for extraction of aggregates, aggregates with quality below the requirements for use and inaccessibility to aggregates are bound to limit the resource's availability.

A potential solution to fulfill the demand of natural resources along with its rapid consumption can be found in utilizing agricultural waste - oil palm shell (OPS) and coconut fibre (CF). Both of these materials belong to the palm shell family and are abundantly available in warm and humid regions of the world such as Africa, Asia and America [7].

It was claimed that over half of the world's total oil palm output originates from Malaysia, and was predicted to grow exponentially as the world's demand for oil increases [8]. The mass production of palm oil and its solid waste, OPS are linearly equivalent. M.N. Amiruddin [9] reported an annual production of 2.6 million tonnes of OPS from the extraction of palm oil creating a major disposal problem. Substituting aggregates with OPS is a feasible solution to address the sustainability problem in the concrete industry as well as the pollution issue in the agricultural industry. This substitution is deemed to be ideal in lightweight concrete construction as OPS has no tendency to produce toxic substances when bounded in the concrete matrix [10]. In comparison to other lightweight aggregates which requires burning of coal or burning of combustible liquid waste product, OPS does not require any significant energy demand at the preparation stages [11].

One of the advantages of utilizing lightweight aggregate (LWA) concrete is the significant reduction of dead load in construction.

This results in cost savings in handling, transportation and material costs in the construction industry. Lower cost is required to obtain the abundantly available agricultural waste, OPS compared to conventional crushed stones aggregate. LWA concrete is suitable for structural and non-structural elements that do not require high compressive strength such as pavements, floors and wall panels [10].
The compressive strength of water cured OPS concrete was observed from tests [5] to be 20.1-24.2 N/mm^2 at 28-day. These values obtained are within the range of lightweight concrete, which is 17- 35 N/mm^2 [12]. The strength of OPS aggregate and its physical bonding strength between the OPS and cement paste are important factors that could determine the concrete's compressive strength failure. At the early ages, up to 56 days, OPS aggregate strength has been observed to be the main factor for concrete's compressive strength failure while the bonding strength between OPS and cement paste governs at 90 days [5]. Basri, Mannan and Zain [10] also agreed on the importance of OPS aggregate strength in determining the concrete strength from the observation made on the breakage of individual OPS aggregate. The compressive strength of OPS concrete was observed to be approximately 42% lower as compared to normal weight concrete (NWC) at 28-day and at 41% at 56-day [10]. Olanipekun, Olusola and Ata [7] indicated a reduction in compressive strength as the percentage of OPS replacement increases. Using the mix design of cement: sand: aggregate ratio of 1:1:2 and water-cement ratio of 0.5, OPS aggregates replacement at gradation of 25%, 50% and 75% have resulted in a 30%, 42% and 50% reduction in compressive strength as compared to NWC.
The combination of smooth surface texture and the porosity of the OPS aggregates surface develop an anchorage for good bondage between the aggregates and the matrix. This phenomenon occurred by the suction of the mortar into surface pores whereas the smooth surface of OPS aids in a better workability as compared to NWC [13]. Furthermore, rough and spiky edges of crushed OPS form a stronger bond between the OPS and the concrete paste [14]. Yap et al. [15] reaffirmed this statement that the compressive strength in the crushed OPS concrete was 16% higher than that of the uncrushed sample at 28-day curing age. Additionally, the percentage of fibre content on the old OPS is usually less than 5% while more than half of fresh OPS grains have fibre content on its surface [11]. Old OPS was, however, preferred over fresh OPS as lesser water demand was needed with the minimal fibre content. Besides, the contact area between mortar and OPS surface was better and thus resulting in a better interfacial transition zone comparatively. Subsequently, compressive strength was benefited.
In view of the abovementioned benefits, an investigation was carried out to explore the potential of utilizing multiple agricultural waste products such as coconut fibre and oil palm shell in concrete in an effort to produce a more environmental friendly and less dense concrete. The mechanical properties of the coconut fibre reinforced concrete at 15% and 25% substitution of conventional coarse aggregate with oil palm shell would be compared with plain concrete and coconut fibre reinforced concrete without substitution of coarse aggregate.

2. Experimental procedures

2.1. Materials

Cement, sand, coarse aggregate, oil palm shell, water and coconut fibre were used to prepare test specimens.
Ordinary Portland cement obtained from YTL cement labelled as high strength cement and certified to MS 522-1 : 2007 (EN 197-1 : 2000), CEM I 42.5N / 52.5N and MS 522 : Part 1 : 2003 was selected. The fine aggregate used was sand mined from a quarry in Mantin. Gravel obtained from a quarry in Kajang was used as coarse aggregate. OPS collected from a crude palm oil factory in Kapar, Klang was used as partial substitution for coarse aggregate. Sieve analysis was carried out to obtain the particle size distribution of fine and coarse aggregates according to Figure 1.

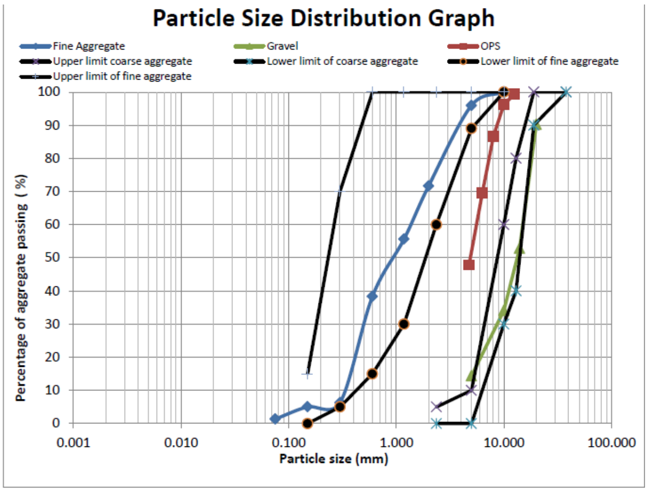

Fig. 1: Particle size distribution of coarse and fine aggregates.

Coconut fibres were collected from a factory in Sabak Bernam, Selangor. The fibre length was within the range of 30 mm to 90 mm. The fibres were oven dried at 160°C for 2.5 hours to minimize the moisture content in the fibres and allowed to cool down for an hour before being used. Apart from oven drying, no processing of the fibres took place.

SYABAS tap water collected from the laboratory was added to the mixes for hydration of cement.

2.2 Mix proportioning

Trial mixes of concrete with characteristic compressive strength of 37 N/mm^2 at 28-day were tested. The selected trial mix is TM 2 which exhibited a 7-day average compressive strength of 20.4 N/mm^2 and a 28-day average compressive strength of 29.5 N/mm^2.

Table 1: Mix proportion of selected trial mix TM 2.

Cement (kg/m^3)	Water (kg/m^3)	Fine aggregate (kg/m^3)	Coarse Aggregate (kg/m^3)
430	215	650	1105

Table 2: Mix Proportion of the Control Mixes and Mixes with Coarse Aggregate Replacement

Batch	Mix ID	Cement	Fine aggregate	Coarse aggregate	OPS	Coconut fibre
		(kg/m^3)				
I	PC	430	650	1105	0	0
II	0.2CF	430	650	1105	0	2
III	0.2CF-15OPS	430	650	939	65	2
IV	0.2CF-25OPS	430	650	829	108	2

Batch I: Plain concrete (PC)
Batch II: 0.2% fibre volume fraction concrete (0.2CF)
Batch III: 0.2% fibre volume fraction concrete with 15% OPS aggregate replacement (0.2CF-15OPS)
Batch IV: 0.2% fibre volume fraction concrete with 25% OPS aggregate replacement (0.2CF-25OPS)

2.3 Testing methods

After casting, the specimens were water cured in accordance to BS EN 12390- 2:2009 [16] until the age of testing. At the testing age, specimens were removed from the curing tank and surface dried with a piece of cloth. Each specimen was then weighed and the respective density was calculated. Compressive strength test was done on cubes of 100mm x 100mm x 100mm size and cylinders of 150mm diameter and 300mm height. Specimens were placed vertically on the platform of the SERVOCON compression machine of 30 tons capacity. Load was continuously and uniformly applied without shock at the rate of 3 kN/s and 5.3kN/s for cube and cylinder specimens respectively until failure. The maximum load applied at failure of the specimen was recorded.

Flexural tensile strength test was done on prisms of size 100mm x 100mm x 500mm using the four-point load test in accordance to BS EN 12390-5. The maximum load at failure of the prism, P was recorded.

3. Results and discussion

3.1. Compressive strength

3.1.1. Cube compressive strength at different curing ages

Cube specimens were tested in accordance with BS EN 12390-3:2009. The average compressive strength of two water cured specimens made from the same concrete mix and tested at the same age are presented in Table 3.

Table 3: The average compressive strength of cube specimen

Batch	Mix ID	Average compressive strength, f_{cu}, (N/mm^2)		
		7-day	28-day	60-day
I	PC	32.82	41.30	42.56
II	0.2CF	37.55	39.59	48.78
III	0.2CF-15OPS	12.06	32.81	37.80
IV	0.2CF-25OPS	28.40	34.10	34.47

<u>At early age: 7-day</u>

With the addition of 0.2% coconut fibre volume fraction (0.2CF), an increment of 14.41% in compressive strength was noted in comparison to PC. Although with a different mix design and fibre aspect ratio, similar observation [17] was also made on the improvement on compressive strength of CFRC with volume fraction of fibre ranging from 0.5% - 2.0%. The compressive strength of 0.2CF-15OPS and 0.2CF-25OPS had shown a significant decrease of 63.25% and 24.37%, respectively, in reference to 0.2CF.

<u>At 28-day</u>

The compressive strength of all the mixes increased with curing age, however, it was noted that the rate of increment varies. At 28-day curing age, PC has shown a 25.84% increment from its 7-day strength and overtaking 0.2CF where only a 5.43% increment was recorded bringing PC to the top of the compressive strength comparison. Nonetheless, it is worthwhile to note that the compressive strength of PC at 40.30 N/mm^2 is higher than its designed strength of C30/37.

0.2CF-15OPS has experienced a remarkable leap of 172% increment compared to its 7-day strength. From this result, it is believed that the low compressive strength of 0.2CF-15OPS at 7-day may be due to poor compaction of the cube specimens.

0.2CF-25OPS exhibited a slightly higher compressive strength compared to 0.2CF-15OPS at this curing age with a 20.07% increment from its 7-day strength. An unpredicted relationship between percentage of OPS aggregate replacement and its compressive strength at the early stage (7 to 28 days) was found.

Table 4: Percentage reduction in compressive strength of concrete with OPS substitution with and without fibre reinforcement as compared to plain concrete

Concrete with 25% OPS substitution	Cement: sand: aggregate	Water-cement ratio	Compressive strength (N/mm^2)		Percentage of reduction in compressive strength
			Plain concrete	Composite concrete	
Olanipekun et al. (2006) Without fibre reinforcement	1:1:2	0.5	35	24	30%
This investigation (2015) With 0.2% coconut fibre reinforcement	1:1.51:2.57	0.5	41.30	34.10	17%

A comparison with respect to compressive strength of concrete cast with 25% OPS substitution was made between the test carried out on concrete cast without fibre reinforcement by Olanipekun et al. [7] and the results from this investigation – concrete cast with 0.2% fibre reinforcement at 28-day strength (Table 4).

Comparing the rate of reduction in the compressive strength shows that specimen 0.2CF- 25OPS in this investigation experiences 17% drop with reference to plain concrete while the OPS concrete in Olanipekun et al. [7] experienced a 30% reduction in compressive strength as compared to its plain concrete. From the analysis, it can be deduced that OPS concrete when reinforced with a low amount of fibre improves its compressive strength significantly.

<u>At later age: 60-day</u>

PC only increased 3.05% while 0.2CF experienced a 23.21% increase from their respective 28-day strength. This result has set 0.2CF steadily above PC in compressive strength at later curing age. Similarly observations was made by M.Ramli et al. [18] that the low volume of incorporation of coconut fibre, 0.6% of coconut fibre by binder volume was found to significantly benefit the strength of the concrete. However, it is important to note that volume of fibre incorporation improves the strength but only to a certain extent. M.Ramli et al. [18] has warned that in their design with a 2.4% fibre volume fraction, the compressive strength resulted in a lower strength as compared to the control.

At 60-day, 0.2CF-15OPS and 0.2CF-25OPS increased by 15.21% and 1.09% respectively from their respective 28-day strength. This shows that 0.2CF-15OPS overtakes 0.2CF-25OPS in compressive strength as compared to the early ages. By replacing 15% of conventional aggregates with OPS aggregates by volume in the CFRC, an 11.18% drop was noticed with reference to PC. With a further increment in the aggregate replacement at 25% level of OPS substitution, a 19% drop was observed in compressive strength as compared to PC.

3.1.2. Cylinder compressive strength at different curing ages

Cylindrical specimens were tested in accordance with BS EN 12390-3:2009 [16]. The average compressive strength of two water cured specimens made from the same concrete sample and tested at the same age are presented in Table 5.

Table 5: The average compressive strength of cylinder specimen

Batch	Mix ID	Average compressive strength, f_c (N/mm^2)		
		7-day	28-day	60-day
I	PC	24.92	31.70	34.86
II	0.2CF	12.78	28.69	33.97
III	0.2CF-15OPS	19.69	24.13	21.55
IV	0.2CF-25OPS	22.44	24.68	25.73

It is observed from tests that cylindrical compressive strength of PC and 0.2CF25-OPS mixes at 7-day are at about 80% of their cube strength, respectively. However, the cylindrical compressive strength of 0.2CF at 7-day has a rather low compressive strength, showing only 34% of its cube strength. Improper compaction could be the cause of the low reading in cylindrical compressive strength. The cylindrical strength of 0.2CF-15OPS at 7-day was found to be 1.63 times higher than its cube strength. This result reaffirms the error in the 0.2CF-15OPS cube specimens at 7-day. However, the cylindrical compressive strength of all mixes collected at 28-day were found to be in the range of 70-80% of their respective cube strength.

At 60-day, cylindrical strength of PC, 0.2CF and 0.2CF-25OPS were 81.9%, 69.6% and 74.6% of their cube strengths, respectively. An error can be determined in cylindrical strength of 0.2CF-15OPS at 60-day as it exhibited a lower strength than its 28-day strength and only possesses 57% of its cube strength.

Based on both the cube and cylindrical compression test results, concrete cast with OPS substitution has lower compressive strength than that of plain concrete even though it was reinforced with CF. The reduction in strength might be due to the lower strength, stiffness, thickness and density of OPS as compared to gravel. Furthermore, the irregular shape of OPS could also be an obstruction in achieving full compaction of OPS concrete resulting in a lower strength of concrete.

3.2. Flexural tensile strength

Prism specimens were tested in accordance to BS EN 12390-5:2009 [16]. The average of two water cured specimens cast from the same concrete mix and tested at the same age are presented in Table 6.

Table 6: The average flexural tensile strength of prism at different curing age

Batch	Mix ID	Average flexural tensile strength, f_{ct}(N/mm^2)		
		7-day	28-day	60-day
I	PC	<3	3.78	3.66
II	0.2CF	4.44	5.85	6.39
III	0.2CF-15OPS	3.51	4.35	4.92
IV	0.2CF-25OPS	<3	4.47	4.38

<u>At early age: 7-day</u>

From the four-point flexural test, the flexural tensile strength of PC and 0.2CF-25OPS at 7-day were noted to be below 3 N/mm^2. At 7-day, the concrete with addition of 0.2% fibre volume fraction, 0.2CF resulted in flexural strength of 4.44N/mm^2. It was observed that with 15% of OPS substitution in the CFRC, the flexural strength of concrete reduced by approximately 21% in reference to 0.2CF.

<u>At 28-day</u>

At 28-day, 0.2CF showed a significantly high flexural strength of 5.85 N/mm^2, 54.76% more than PC strength. With 15% and 25% OPS aggregate replacement in the CFRC, a drop of 25.64% and 23.59% in reference to 0.2CF were observed, respectively. At 28-day, flexural strength of 0.2CF was at the peak, followed by 0.2CF-25OPS, 0.2CF-15OPS and PC. Both the concrete cast with 15% and 25% OPS volume replacement exhibited higher flexural strength than PC.

This observation, however, contradicts with M.A. Mannan and Ganapathy [5] where flexural strength of OPS concrete was lower than the plain concrete under water curing. It is believed that such phenomenon derives from the inclusion of coconut fibre in the current investigation. Similar observations were made in recent investigations [17] where flexural tensile strength of CFRC with 2% fibre volume fraction was also found to be higher than that of plain concrete. Although the design of CFRC mix are different, both design shown in Table 7 have observed an increment in flexural strength as compared to their respective plain concrete. The common ground of these two mixes would be the low volume content of coconut fibre in the concrete matrix.

Table 7: Pure coconut fibre reinforced concrete design of Baruah and Talukdar (2007) [17] compared to 0.2CF mix in this investigation

Design	Baruah and Talukdar (2007) [17]	This investigation
Cement: sand: aggregate	1:1.67:3.64	1:1.51:2.57
Water/cement ratio	0.535	0.5
Fibre length (mm)	40	30-90
Fibre diameter (mm)	0.4	0.23
Fibre volume fraction (%)	2	0.2
Prism size (mm^3)	150x150x700	100x100x500
Flexural tensile strength of CFRC (N/mm^2)	3.25	3.78
Flexural tensile strength of CFRC (N/mm^2)	4.16	5.85

<u>At later age: 60-day</u>

The flexural strength of PC and 0.2CF-25OPS at 60-day were noted to have a 3.17% and 2.01% drop as compared to their respective 28-day strength. It is worth noting that the flexural tensile strength of CFRC with partial OPS aggregate replacement has reduced slightly in reference to the pure CFRC. However, the flexural tensile strength of both 0.2CF-15OPS and 0.2CF-25OPS turned out to be higher than that of PC.

3.2.1 Experimental value versus value obtained empirically

Reviewing the 28-day results, flexural strength of PC was close to 10% of its compressive strength, as expected. Flexural strength of concrete reinforced with coconut fibre, 0.2CF, 0.2CF-15OPS and 0.2CF-25OPS lie in the range of 13-15% of their compressive strength. The comparison between the two approaches are tabulated in Table 8.

Table 8: The differences between experimental and empirical value in flexural strength of different mixes

Batch	Mix ID	Flexural Strength (N/mm^2)	
		Experimental value at 28-day	Empirical value [10% of compressive strength]
I	PC	3.78	4.13
II	0.2CF	5.85	3.96
III	0.2CF-15OPS	4.35	3.28
IV	0.2CF-25OPS	4.47	3.41

3.3. Density

The densities of cube specimens were calculated using the average of two cubes for each curing age and the results are tabulated in Table 9.

Table 9: Average cube density of different mixes at different curing ages

Batch	Mix ID	Average density (kg/m^3)		
		7-day	28-day	60-day
I	PC	2371	2410	2400
II	0.2CF	2433	2419	2450
III	0.2CF-15OPS	2368	2405	2385
IV	0.2CF-25OPS	2263	2278	2281

Among all mixes, 0.2CF exhibited the highest density as expected. The slight increase in density of this mix as compared to PC is believed to derive from the inclusion of 0.2% fibre volume fraction in the concrete matrix. Similar observation has been made by Sayyad and Patankar [19] where the density of concrete has been observed to increase with the increment of steel fibre volume fraction in the geopolymer composite concrete. The increment of density with the increase in fibres volume fraction can be explained by good particle packing which leads to reduction in air content.

The partial aggregate replacement using OPS has lowered the density of the concrete. It was observed that the higher the percentage of OPS replacement, the lighter the concrete. The reduction in weight can be justified by a lower density of OPS, 1000 kg/m^3 as compared to the density of conventional crushed stone aggregate, 2552 kg/m^3.
PC has an average density of 2394 kg/m^3. The concrete mixes with 0.2CF-15OPS and 0.2CF-25OPS have experienced a drop of approximately 0.5% and 5%, respectively, in density with reference to PC. The slight reduction in density was not significant to be deemed as lightweight concrete. Among the criteria of a lightweight concrete includes having air dry density not exceeding 1840 kg/m^3 and strength above 17 N/mm^2 as determined by ASTM C 567.

3.4. Young's modulus analysis

In this investigation, Portable Ultrasonic Non Destructive Instrument Tester (PUNDIT) was used to measure the homogeneity, quality and elastic modulus of the concrete.
The average density of the two prisms at 60-day curing age was calculated. With the obtained wave velocity, V, dynamic modulus of elasticity, $(\boldsymbol{t})$ was calculated and then converted to Young's modulus, $\boldsymbol{Ecm}$. The results are presented in Table 10.

Table 10: Density ρ, wave velocity V, dynamic modulus of elasticity Ec (t) and Young's modulus Ecm at 60-day curing age

Batch	Mix ID	ρ (kg/m^3)	V (m/s)	$Ec(t)$ (GPa)	Ecm (GPa)
I	PC	2362	4662	46.23	44.03
II	0.2CF	2482	4854	52.63	50.13
III	0.2CF-15OPS	2337	4687	46.21	44.01
IV	0.2CF-25OPS	2363	4473	42.56	40.53

Ultrasonic pulse velocity (UPV), also known as wave velocity, V was found to be dependent mainly on the elastic properties of the material. A low reading on pulse velocity compared to that of a sound specimen would indicate a presence of void along the pulse path. It is known that the pulse velocity obtained from PUNDIT test can indicate the condition of the concrete. The quality of concrete with pulse velocity between 3660 to 4570 m/s is classified as 'generally good' while concrete with pulse velocity above 4570 m/s is considered as 'excellent' [20]. Referring to this tentative classification, the quality of PC, 0.2CF, 0.2CF-15OPS concrete are classified in the category of 'excellent' while the quality of 0.2CF-25OPS is considered to be 'generally good'. It should be noted that the relationship drawn between pulse velocity and condition of concrete was established on the basis of normal weight concrete with density of about 2400 kg/m^3. Nevertheless, with the introduction of foreign materials, coconut fibre and OPS into the concrete, the pulse velocity remained comparatively high.
Shafigh et al. [4] stated that as compared to normal weight concrete, Young's modulus E_{cm} of OPS lightweight concrete is very much lower. A drop of 8% in the Young's modulus of concrete has been observed when 25% by volume of coarse aggregates was replaced with OPS aggregates. This low modulus of elasticity may affect the deflection in structural member.
Another method of obtaining the Young's modulus value, E_{cm} can be found using equation 1 according to EN 1992-1-1:2004 [21].

$$E_{cm} = 22[\frac{fcm}{10}]^{0.3} \tag{1}$$

where,
Ecm is the Young's modulus of the concrete, also known as modulus of elasticity (GPa)
fcm is the mean value of concrete cylindrical compressive strength (N/mm2)

A comparison made between Young's modulus value, Ecm obtained from PUNDIT test and equation (1) is shown in Table 11.

Table 11: Comparison of Young's modulus value obtained from two different methods for batch I, II, III and IV at 60-day

Batch	Young's modulus, E_{cm} (GPa)	
	PUNDIT	Equation (1)
I	44.03	32.00
II	50.13	31.75
III	44.01	27.70
IV	40.53	29.21

The results obtained from PUNDIT test were found to be higher than those derived from equation (1). However, in both approaches, the Young's modulus of CFRC with OPS aggregate has exhibited lower value than PC. A low modulus of elasticity would allow higher deflection and make the concrete more flexible to bending.

4. Conclusion

Experiments have been conducted to investigate the mechanical properties of coconut fibre reinforced concrete (CFRC) partially replaced with lightweight aggregate, oil palm shell (OPS). The mechanical properties investigated include compressive strength of cube $f c$u, compressive strength of cylinder fc, flexural strength fct, density ρ and modulus of elasticity Ec. These properties were compared with the mechanical properties of control samples, plain concrete (PC) and also pure CFRC with 0.2% of fibre volume fraction (0.2CF).
It was found that the use of multiple agriculture waste, such as, coconut fibre (CF) and oil palm shell (OPS) in concrete mix affected the concrete compressive strength, flexural tensile strength, density and Young's modulus. It was noted that presence of 0.2% of CF increased the concrete cube compressive strength, but addition of OPS reduced the strength. The simultaneous addition of CF and OPS has resulted in an increase in the flexural tension strength of concrete prisms, while, specimens cast with CF alone exhibited further increments in the long run. Similar observations were noted in the Young's Modulus, where specimens cast with CF exhibited high Young's Modulus value comparatively. With respect to concrete densities, specimens cast with 25% OPS inclusion exhibited the lowest density while those added with 0.2% CF alone exhibited the highest density. In all cases, the concrete specimens cast in this investigation exhibited with normal concrete strength, 34 to 48 N/mm^2.
Even though the ultimate strength of CFRC is biased towards 15% OPS substitution, 0.2CF-25OPS is deemed to be a feasible mix in creating a more environmental friendly, lighter weight structural or non-structural concrete element. Furthermore, utilizing 0.2CF-25OPS mix in the application of elements such as wall panels, kerbs and pavement will not only reduce the use of crushed aggregates in a large scale but also reduces the transportation and handling cost significantly with its low density characteristic. In a nutshell, a more sustainable concrete can be produced with 0.2CF-25OPS mix in terms of reducing the dependency on conventional crushed aggregate while putting agricultural waste, OPS into good use.

Acknowledgement

The authors acknowledge the University of Nottingham Malaysia Campus for providing the facilities to carry out the research.

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